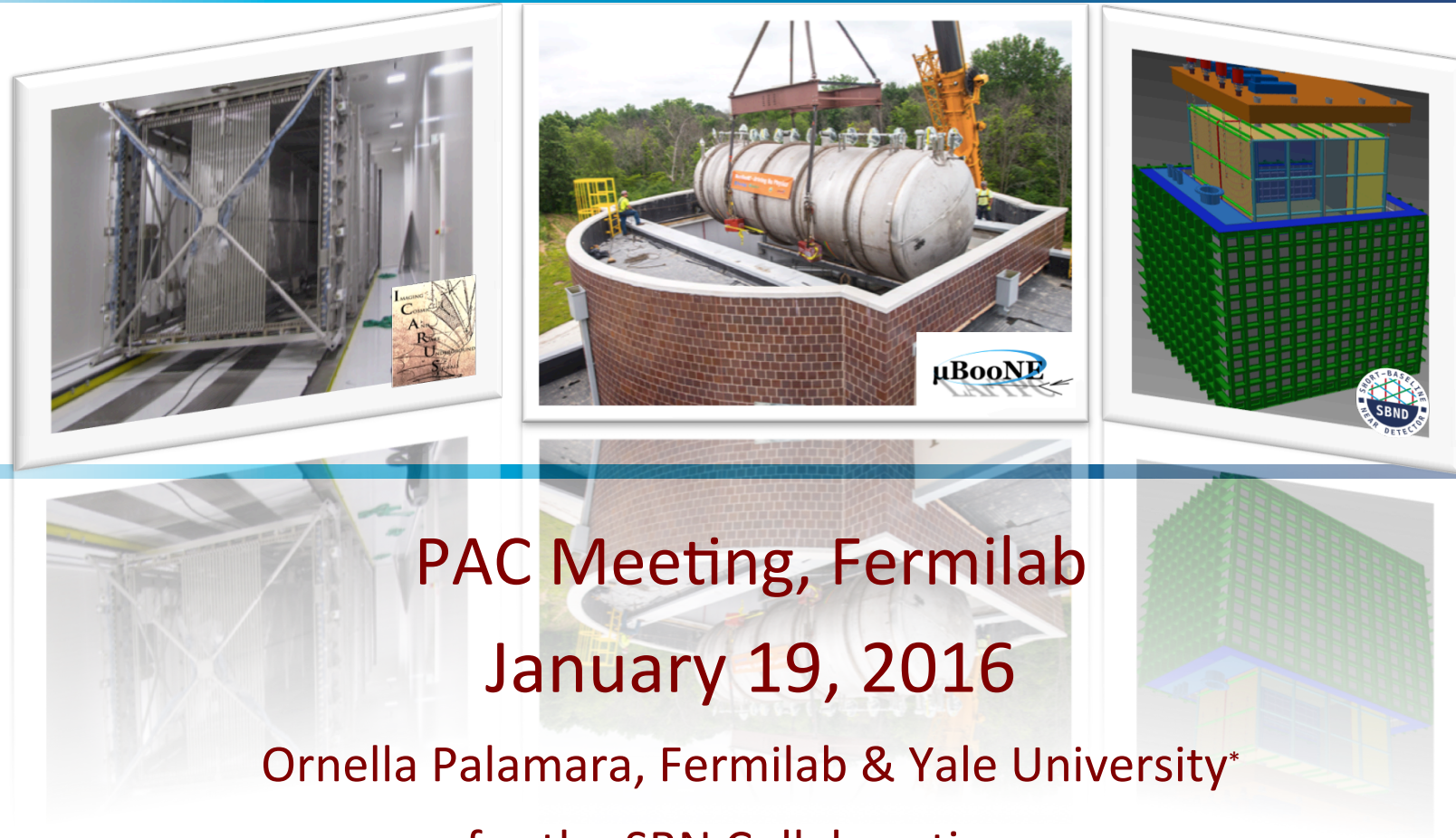


# The Analysis and Software Infrastructure Status/Plans



\*on leave of absence from INFN, Laboratori Nazionali del Gran Sasso, Italy

# Outline: SBN Efforts toward Coordinating Plans

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## ❑ Ongoing Analysis Efforts and SBN Coordination across the three experiments – Current Status and Plans

- *Analysis/Software Development:*
  - Common LAr software environment
- *Analysis Efforts:*
  - Surface operation and cosmic background mitigation → Task Force on Cosmic Ray Mitigation for SBN Detectors
  - Physics of the BNB upgrade → Studies of oscillation sensitivities for different beams configurations (upgrades of the BNB beamline)
- *Technical Coordination:*
  - DAQ and online systems
  - Cosmic ray taggers
  - Photon detectors



# Science Goals of the SBN Program

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- ❑ Directly follow-up on the MiniBooNE neutrino anomaly by utilizing the LArTPC technology to determine the composition of the observed excess as electrons or photons (Phase I)
- ❑ Apply the advantages of the LArTPC technology and *multiple detectors at different baselines* to the question of high- $\Delta m^2$  sterile neutrino oscillations, testing current allowed oscillation parameters at  $\geq 5\sigma$  (Phase II)
- ❑ Study  $\nu$ -Argon interaction physics using millions of events from both the Booster and Main Injector neutrino beams at Fermilab
- ❑ Further develop the LArTPC technology toward applying it at very large scales for long-baseline physics in DUNE

# The SBN Proposal

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Scientific proposal and conceptual design report for the  
SBN program (Jan 2015)

**A Proposal for a Three Detector  
Short-Baseline Neutrino Oscillation Program  
in the Fermilab Booster Neutrino Beam**

Submitted jointly by ICARUS, MicroBooNE and SBND (LAr1-ND)

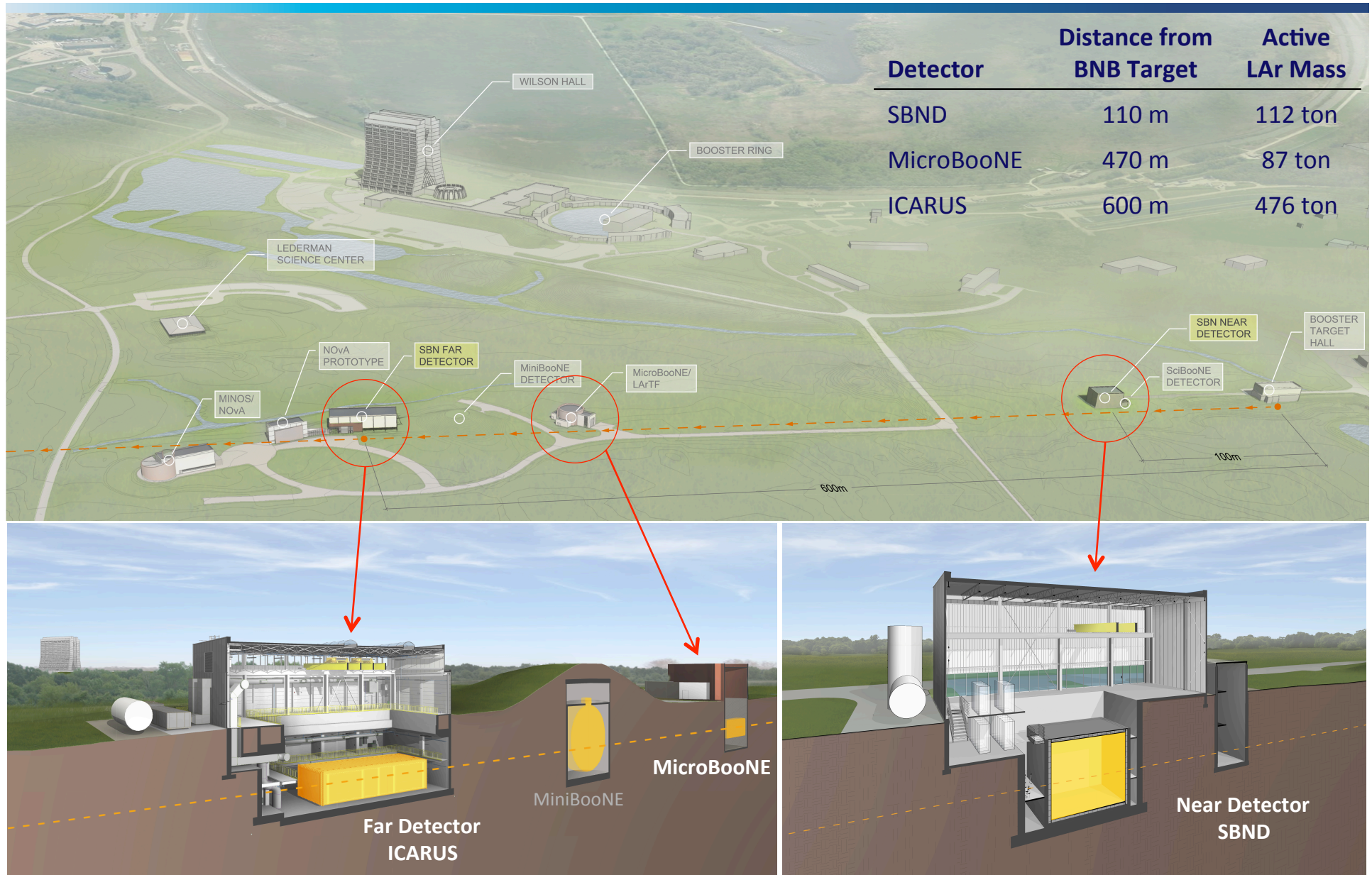
<http://arxiv.org/abs/1503.01520>

- Part I: SBN Physics Program
- Part II: Near Detector Conceptual Design
- Part III: T600 Design and Refurbishing
- Part IV: Infrastructure and Civil Construction
- Part V: Booster Neutrino Beam
- Part VI: Coordination and Schedule

*218 authors from  
22 US and 23 non-US  
institutions*

Collaborations have all  
continued to grow  
through 2015

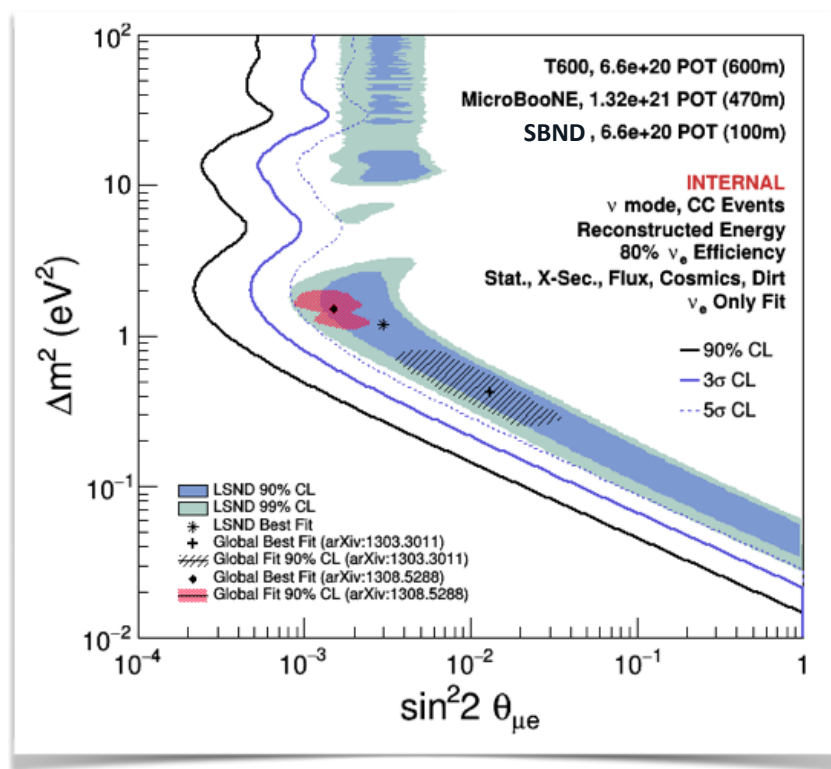
# The Three-Detector SBN Program



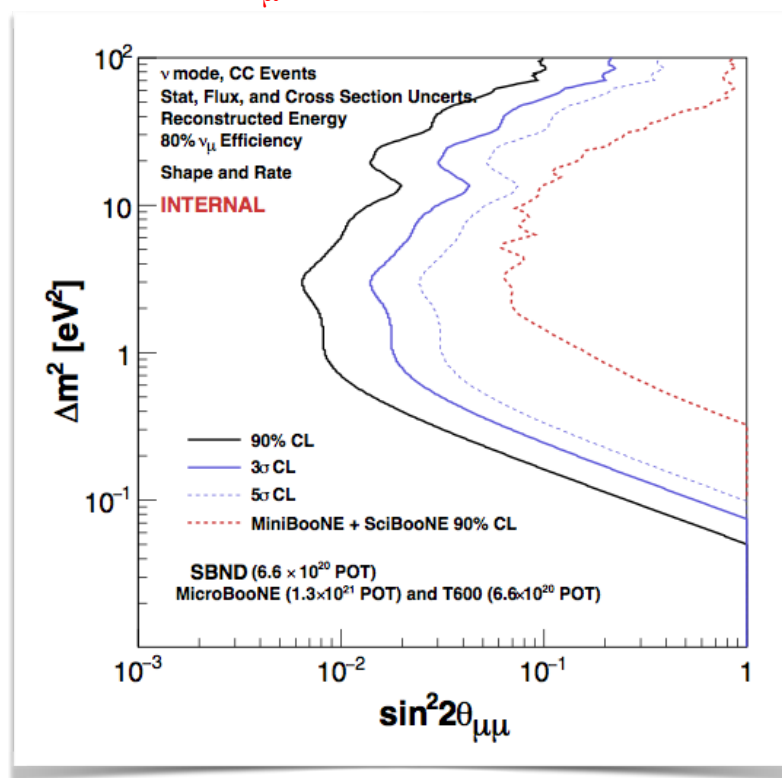
# Physics Reach of the SBN Program

- ❑ Oscillation sensitivity of the SBN program has been evaluated in a joint effort by three collaborations
  - *Based on full simulations of all known backgrounds and systematic uncertainties*

## $\nu_e$ Appearance



## $\nu_\mu$ Disappearance





# Since January 2015

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## ❑ Development of the SBN physics proposal

- *Spearheaded by a five member Task Force representing FNAL, CERN, and the three collaborations as well as a set of Working Groups with co-conveners and members from each of the collaborations*
- *4 WGs: flux and systematics, cosmics, cryogenic infrastructure, civil construction*

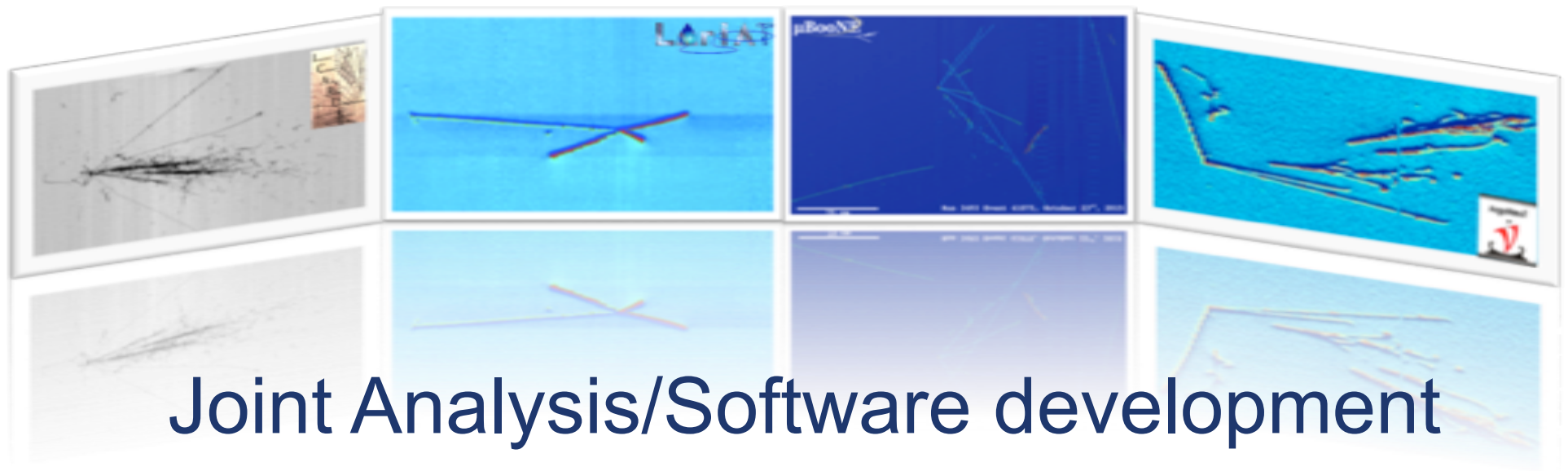
## ❑ Following the proposal

- *SBN Executive Board consisting of collaboration spokespersons and SBN Program Coordinator formed to facilitate continued communication*

## ❑ With Stage 1 approval granted after the January 2015 PAC, focus of collaborations has been on detector design, construction, and operation - **Excellent technical progress in 2015!**

## ❑ Analysis and software development has continued in parallel with both short- and long-term aims

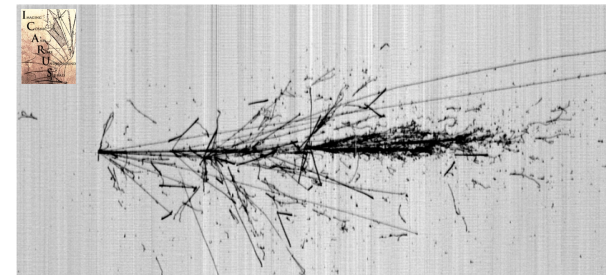
- *Emphasis tends to be where input is needed for detector or program design... e.g. →*



# Reconstruction/Analysis Software Coordination

## ❑ Software development effort - Continued Analysis Tool development

- *LArSoft provides a common software infrastructure for the sharing of reconstruction and simulation codes used by different liquid argon TPC experiments*
  - ArgoNeuT, MicroBooNE, LArIAT, SBND, DUNE, etc. use the LArSoft framework
- *ICARUS developed their own analysis software for the Gran Sasso physics run before the start of the LArSoft project*
  - ICARUS reconstruction workshop (July 2015, CERN) included LArSoft experts from Fermilab and reconstruction developers from MicroBooNE to survey and discuss the situation of reconstruction and analysis infrastructures of the experiments and start planning future common steps
  - Representatives of ICARUS attended the art-LArsoft school at Fermilab (August 2015, Fermilab), to improve technical knowledge of the LArsoft framework to help taking a decision on the adoption of a common framework



# Reconstruction/Analysis Software Coordination

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- ❑ LAr TPC Reconstruction workshop (Fermilab October 2015) with all stakeholders
  - *Organized and attended by Fermilab and CERN computing experts together with representatives from all of SBN (MicroBooNE, ICARUS, and SBND), DUNE, and LArIAT*
  - ***Assessment workshop:*** *reviewed current status of reconstruction LAr TPC event reconstruction and analysis. Challenges and lessons learned*
  - ***Requirements workshop:*** *to define requirements for a LArTPC software platform that will support the analysis needs of LArTPC experiments over the next ~decade*
  - *Requirements document now in draft, authored by workshop participants*
    - <https://cdcv.sfnal.gov/redmine/projects/lartpc-requirements/repository/revisions/master/entry/new-document/requirements.pdf>
  - *Some examples: i) physics algorithm performance, ii) ability to use multiple physics algorithms in end-to-end analysis of data, iii) increased functionality of event visualizations, iv) enable effective use of multi-core and new computer hardware technologies, v) ease of use and distribution for international collaborations, vi) inclusion of new external software components such as event generators and hadronic simulation codes*
- ❑ Next step is to plan future work based on published requirements – again involving all participants



# Reconstruction/Analysis Software Coordination

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- ❑ *Steering Group* of experiment spokespeople and software experts (formed over the past 12 months)
  - *Meets with LArSoft team ~monthly to drive developments, prioritize work, and plan for the future*
- ❑ LBNC also working with the groups – to receive reports on assessment, planning and future work for software and analysis for the LArTPC-based experiments

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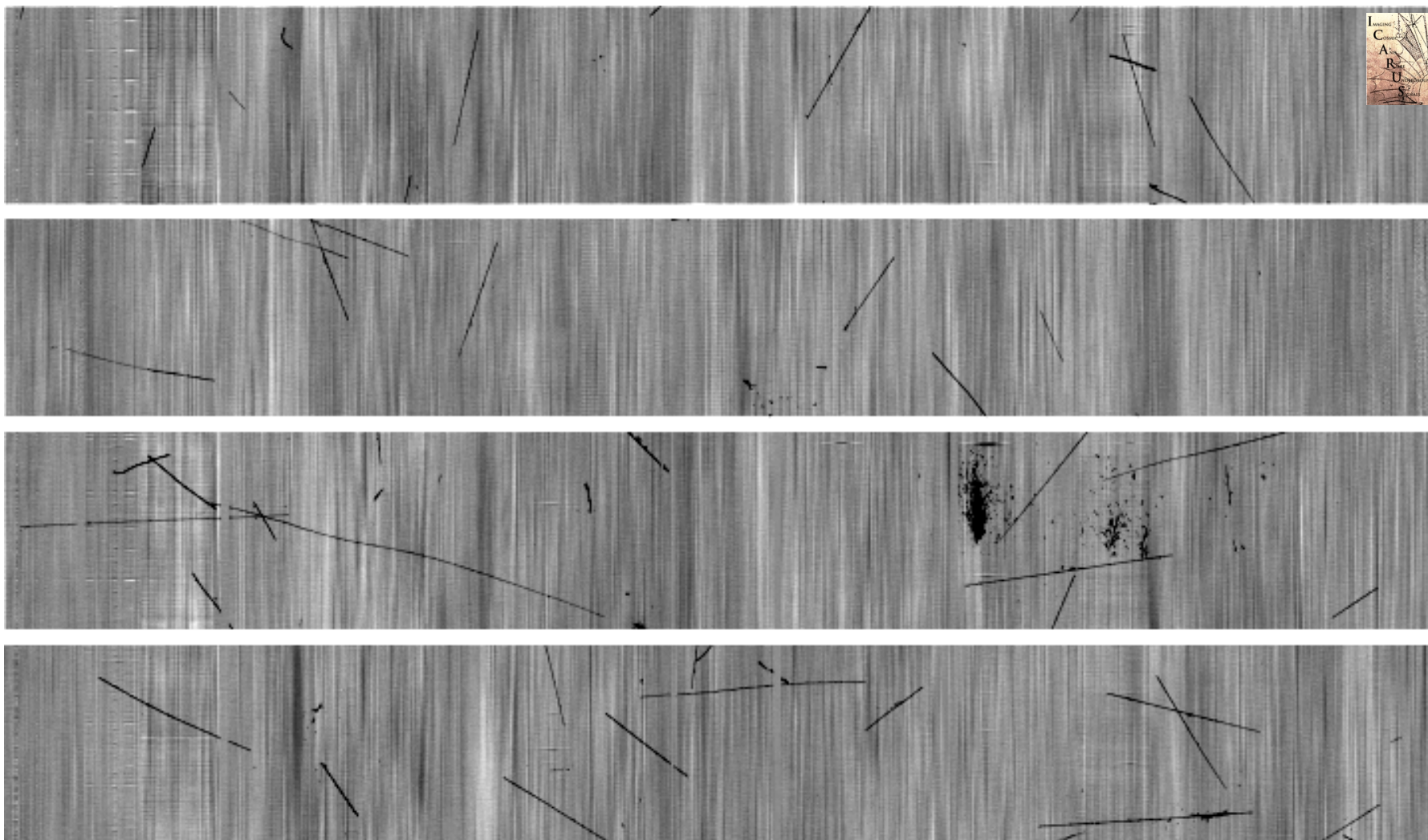
## Joint Analysis Efforts

- *Mitigation of cosmogenic backgrounds*
- *Physics of the BNB upgrade*

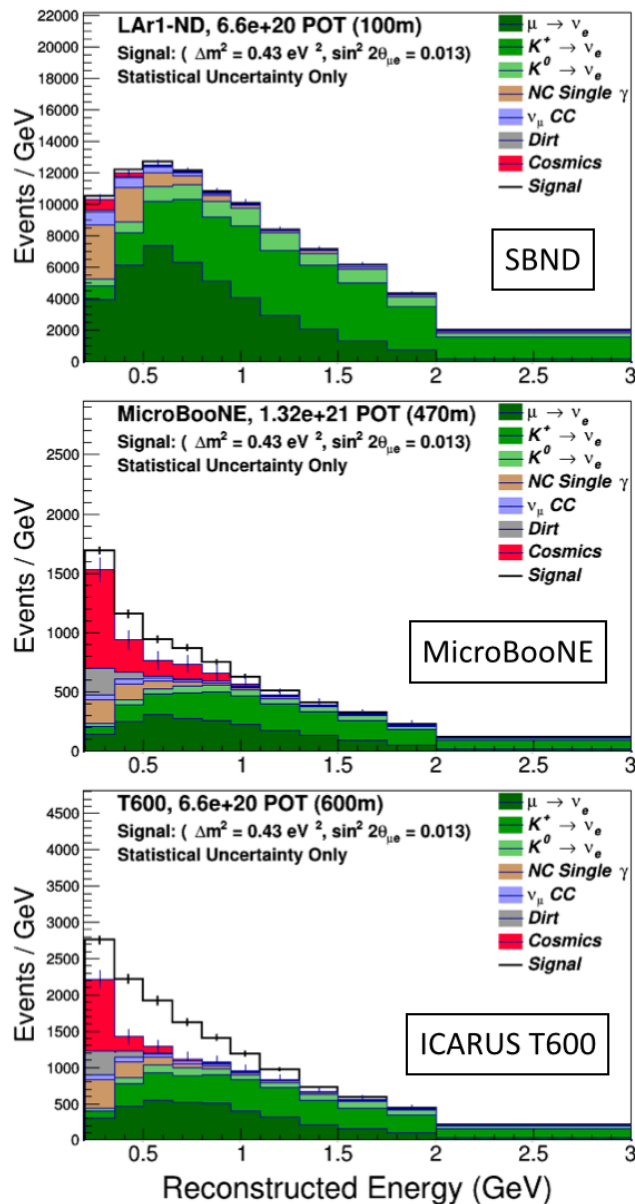
# Cosmogenic Backgrounds

ICARUS T300 - Pavia run - Cosmic rays

Drift time 1.6 ms

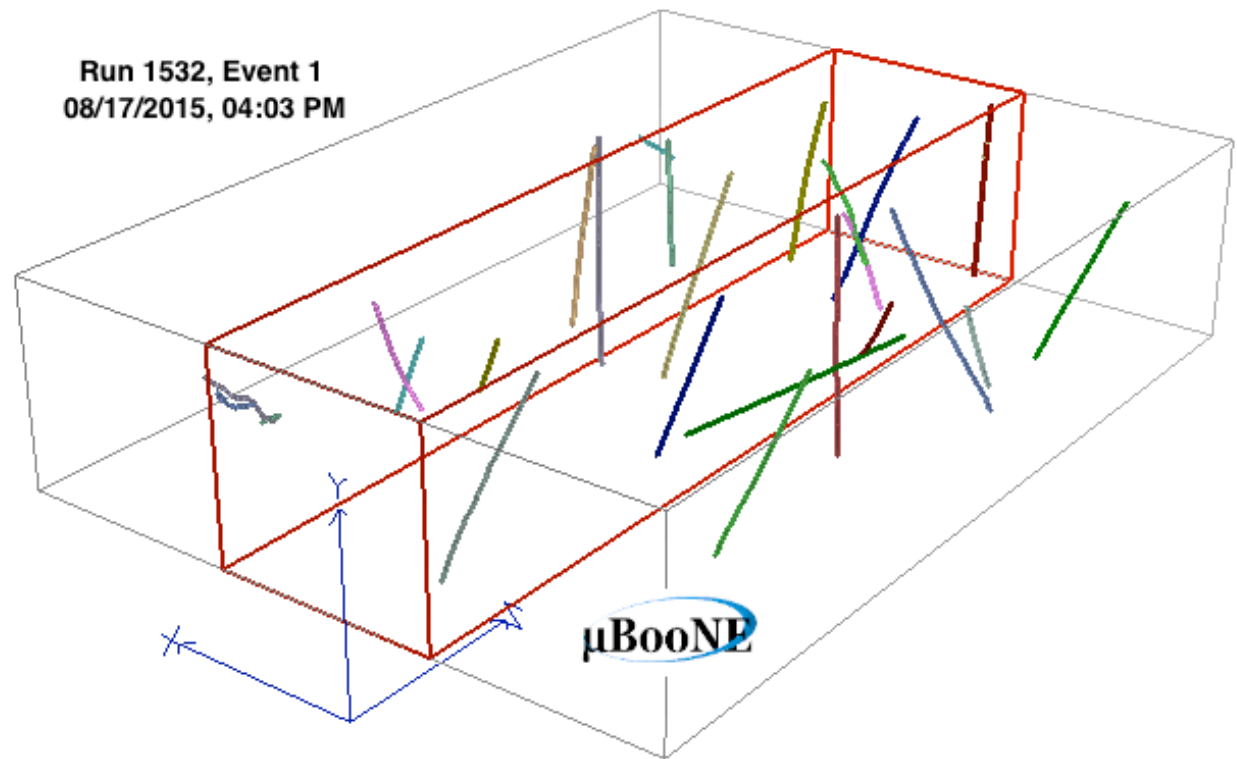


# Cosmogenic Backgrounds



❑ The problem: 1000x longer charge drift time than the beam spill time!

*1.6  $\mu\text{s}$  beam spill vs. 1-2 ms TPC drift time*



MicroBooNE cosmic data  
 with 3D reconstruction!



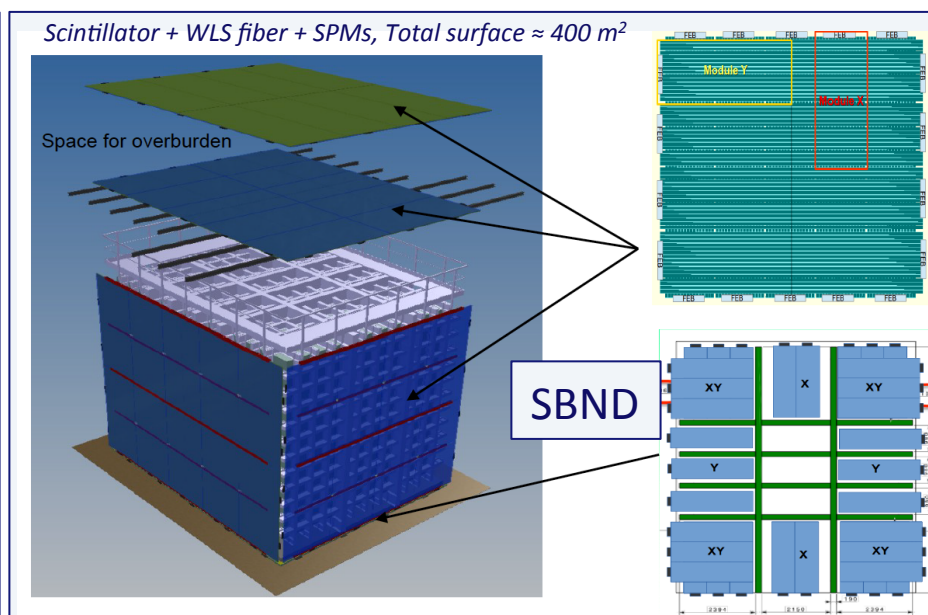
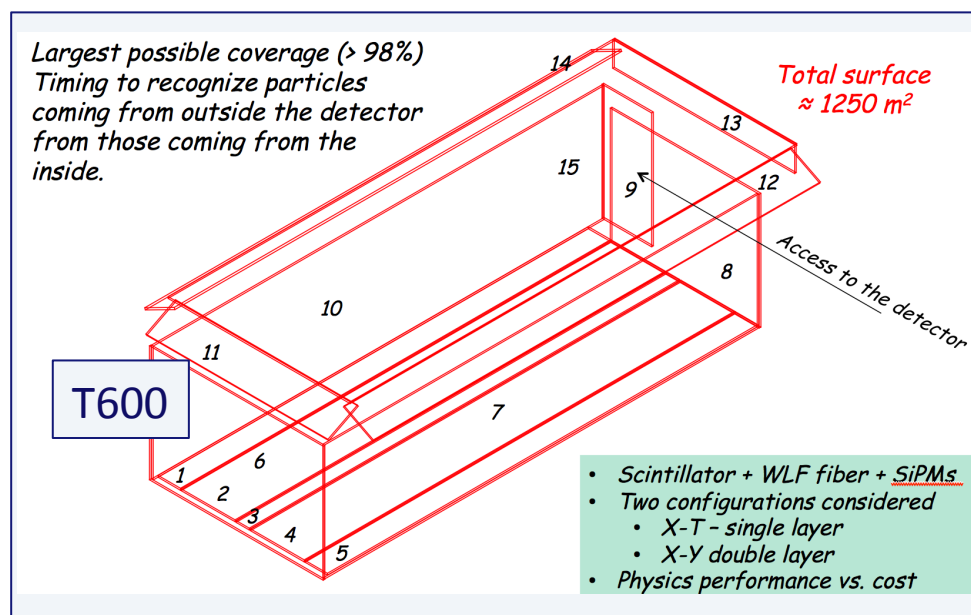
# Mitigation of Cosmogenic Backgrounds

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- ❑ Both the near and far detector buildings have been designed to accommodate up to 3m of concrete shielding directly above the detectors and MicroBooNE has proposed adding overburden
- ❑ Overburden provides significant rejection power for many  $\nu_e$ -like backgrounds induced by cosmic rays other than muons
  - *Near 100% reduction of **primary** protons, neutrons, pions, and gammas that enter the TPCs without OB*
  - *Modest increase in **secondaries** generated in OB (e.g. 1% increase in secondary protons and 7% increase in secondary neutrons with 3m concrete OB according to a recent SBND simulation study)*
- ❑ This leaves photons generated by cosmic muons near or inside the detector as the primary source of cosmogenic backgrounds in the  $\nu_e$  analysis

# Cosmic Ray Taggers (CRT) Design

- ❑ The SBN proposal (Jan. 2015) assumed a 3m concrete overburden and a CRT for both the near and far detectors and MicroBooNE has recently proposed installing a CRT
- ❑ SBND and MicroBooNE CRT are being designed and constructed
- ❑ ICARUS CRT is being designed



# SBN Task Force on Cosmic ray Mitigation

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- ❑ For the SBN proposal (Jan 2015), the three collaborations performed independent simulations to study the impact of cosmic rays, the need of cosmic-ray tagger systems and overburden
- ❑ These simulations have been refined by all three collaborations over the past year to compare/validate those results and push on new studies
  - *MicroBooNE cosmic ray task force started analyzing data*
  - *SBND complete detector geometry in place*
  - *Expanded ICARUS group initiated studies to refine the understanding of the cosmic ray backgrounds for the SBL measurement*
- ❑ Joint Cosmic Ray Mitigation Task Force for SBN Detectors formed in Nov. 2015 to define the requirements and implementation of the overburden and cosmic ray tagger systems for the SBN detectors
  - *Conveners: one representative for each experiment*
  - *Preliminary report next month*

***Joint Task Force*** charged with assimilating available information and performing any new analysis needed to address specific questions related to overburden and CRT systems

# Cosmics Task Force Charge

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- ❑ Main questions that are now being addressed jointly by all the three experiments for each of the detectors
  - *Accurate description of building/detector geometry in the simulations*
  - *Impact and required thickness (1m, 2m, 3m) of the overburden*
  - *Cosmic tagger system (CRT) configuration and performance requirements (spatial granularity, time resolution, number of layers)*
  - *Additional rejection from the cosmic tagger systems relative to internal light collection system*
  - *Impact of activity from secondary particles (from cosmic rays and beam interactions) on cosmic taggers*
  - *Identify areas where common technical solutions for the CRTs could be used for SBND, MicroBooNE and ICARUS-T600, ex.*
    - Already designed SBND readout electronics to be used for all detectors
    - Common scintillator strip size/configuration be used for at least part of the systems
- ❑ Two joint meetings
  - *Working on protocol for internal-documents sharing*



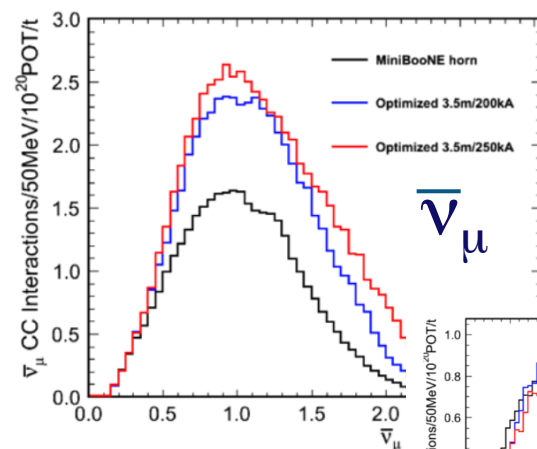
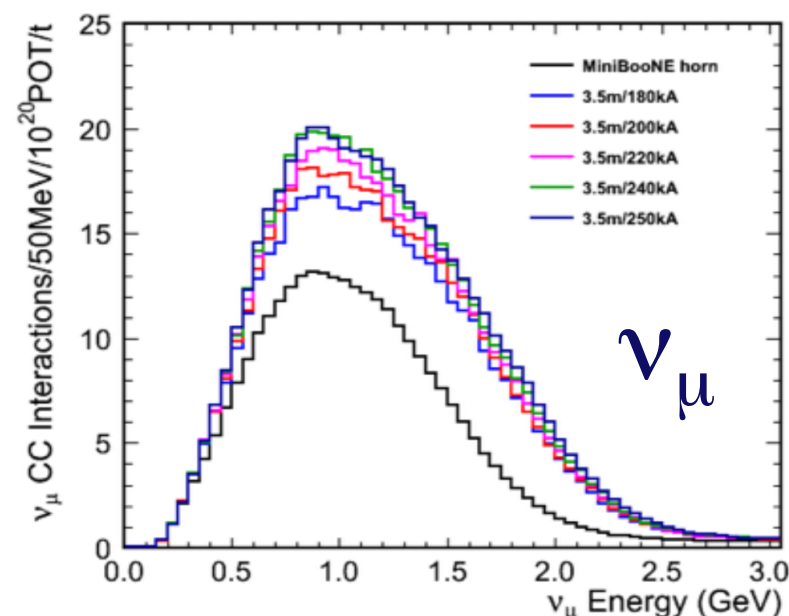
# Validation of cosmic ray simulations

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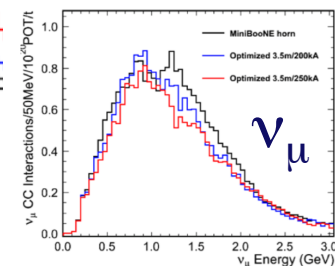
- ❑ Cosmic ray simulations have to be validated with real data
  - *ICARUS is considering the feasibility of setting up a test facility to verify the simulations and expectations for cosmic rays*
  - *MicroBooNE now has cosmic ray data that can be valuable for all three detectors and will make that available for the whole SBN program.*

# Booster Neutrino Beam Improvements

- ❑ Far detector statistics are key to  $\nu_e$  appearance sensitivity
  - *(Detector mass)  $\times$  (Neutrino flux)  $\times$  (Time)*
- ❑ Possible BNB upgrade paths:
  1. *Increase focusing efficiency of target/horn system*
    - Optimize horn length, inner conductor, and current
  2. *Increase rate at which horn system is capable of running*
    - Booster can operate at 15 Hz, existing horn at 5 Hz (limited by mechanical integrity and power supply)
- ❑ Detailed study carried out by design team at FNAL; conclusion: gains up to  **$\sim 1.8\times$  in event rate** possible with longer horn design and upgraded power supply



antineutrino mode running



# Upgrades of the BNB beamline

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- ❑ Following one the recommendations at the December SBN Program Director's Progress Review:

*“Perform simulations to clarify the additional sensitivity reach from the new flux spectrum, quantify at what POT systematics start to dominate, and the dependence on assumptions about NC  $\pi^0$  rejection and cancellation of errors in the near/far ratio.”*

- ❑ Charge SBND, MicroBooNE, ICARUS and BNB experts with addressing the physics reach for different beams configurations (by May 2016)

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# Technical coordination

# Technical Coordination

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## ❑ Cosmic Ray Tagger Systems

- *Common solutions in scintillator tracker design and readout electronics*

## ❑ DAQ

- *Lots of activity involving SBND, MicroBooNE, and ICARUS DAQ experts to consider common DAQ software solutions, data formats, etc.*
- *One-day SBN-DUNE workshop held in November to explore possible synergies within DAQ and readout electronics.*
- *SBN program initiating joint online systems working group with participation from all three collaborations*

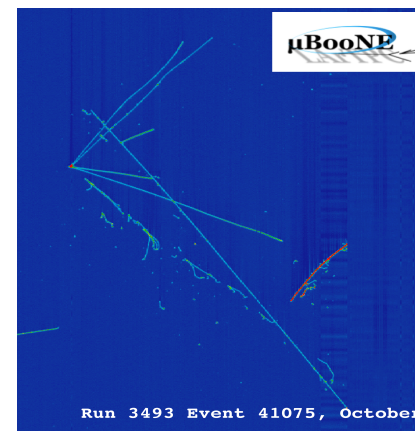
## ❑ Photon Detection

- *SBND working with ICARUS on PMT-based photon detection system*
- *SBND to use same PMTs, 8" Hamamatsu R5912*
- *Plan to send SBND PMTs to CERN for wavelength shifter coating and performance testing/characterization in same facility used for ICARUS tubes*
- *Working together to decide on similar electronics and DAQ system*

# Summary: SBN Analysis/Software coordination

## □ SBN detectors have made enormous technical progress in 2015

- *MicroBooNE is running with beam! SBN phase-I now operational!*
- *ICARUS T600 refurbishment is progressing well and on schedule at CERN*
- *SBND TPC is in final design phase, construction to begin in early 2016*
- *Civil construction on-going*
- *Improved beam designs being explored*



## □ Coordinating plans on analysis

- Common reconstruction and analysis framework is the first step for interconnections/synergies and effective use of resources between different collaborations and it is crucial for the joint analysis of the three SBN experiments
- *Development of a longer-term strategy – in progress*
  - Sharing results of development progress on a continuous base. Ex: Future more extensive workshops devoted to LAr TPC reconstruction
  - Joint Steering Committee
  - Joint Task forces and working groups

**Well on our way to an exciting  
SBN physics program!**